Results from the Palomar Testbed Interferometer (PTI)

The Orbital Dynamics of the Spectroscopic Binary α-Andromedae

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The research described in this poster was carried out by the Jet Propulsion Laboratory, California, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

Abstract

We report on the visual orbit determination of the Spectroscopic Binary, alpha Andromedae, using Palomar Testbed Interferometer (PTI) K-band visibility measurements combined with literature radial velocity determinations. Our data agree well with the results of Pan (1992) made on the Mark III optical interferometer. Using a fixed period of 96.696 days, the **orbital elements** determined are: the angular semimajor axis, *a*" = 24.15±0.13 milliarcseconds., inclination, *i* = 105.59±0.44 degrees, position angle of the ascending node, Ω = 104.18±0.08 degrees, eccentricity, *e* =0.5366±0.0014, Longitude of the Periastron, ω = 77.09±0.44 degrees. The best-fit intensity ratio of 0.234±0.006 and V and K delta magnitudes provide a **V-K color index** of -0.41±0.05 for the primary and 0.01±0.08 for the secondary. Using the semi-amplitudes, K1 and K2 from Ryabchikova (1999) gives a **distance estimate of** 30.3±0.6 pc and an **orbital parallax of** 33.0±0.7 milliarcseconds which compares well with the Hipparcos determined values. The **computed masses of** the primary are 3.8±0.2 M_{sun} and 1.9±0.1 M_{sun}, also in agreement with Pan's numbers. These satisfactory results not only extend the range of PTI into the B spectral class but also extend the range of binary orbit determinations to an angular separation of 24 milliarcseconds.

Introduction

- The Palomar Testbed Interferometer (PTI) has proven to be an efficient probe of the orbital dynamics of spectroscopic binaries (SB) in the H- and K-spectral bands.
- We sought to extend the range of PTI into the B and O Spectral Class regime.
- An especially interesting initial target in this regime was α-Andromedae (HD 358, HR 15), a well-studied double-lined spectroscopic binary (SB2) at B8 IVmnp.
- The maximum separation of the components is 24.15±0.13 milliarcseconds (mas) which makes it the furthest angularly-separated SB system measured by PTI to date.
- We report that PTI can satisfactorily examine the orbital dynamics of late-B SBs.

Alpha Andromedae System Characteristics

- Spectral Class
  - Primary - B8 IV mnp - a chemically peculiar star of the Mercury-Manganese subclass (Palmer, 1968)
  - Secondary - A3 V star (Pan, 1992)
- Absolute Magnitude (Pan, 1992)
  - Primary - $V_{mag} = 0.19 \pm 0.05$
  - Secondary - $V_{mag} = 1.80 \pm 0.06$
- JP11 (Johnson Photometry) for Primary (SIMBAD)
  - V:555 μm = 2.06
  - K:2200 μm = 2.40
- Rotational Velocities (Ryabchikova, 1999)
  - Primary - $v \sin i = 56 \pm 2$ km/sec
  - Secondary - $v \sin i = 110 \pm 5$ km/sec
- T_{eff} for the primary range from 13800 -10200 °K (Ryabchikova, 1999)
  - Primary - 13700 °K for Balmer Jump Region,
  - Primary - 10200 °K for Paschen contimuum
  - Ryabchikova used T_{eff} 13800 °K for primary, 8500°K for secondary
  - We used 13966±0 °K for the primary
- Stellar Radii: $R_A = 2.7 \pm 0.4\ R_{sun}$ $R_B = 1.65 \pm 0.3\ R_{sun}$ (Ryabchikova, 1999)
- Distance (Hipparcos) = 29.8 +/- 0.7 pc Parallax = 33.6 +/- 0.7 mas

Table 1. Alpha Andromedae Analyses Summary

Orbital parameter	Aikman(1976) This Study	Pan(1992)	Tomkin(1995)	Ryabchikova(1999)
Period, days	96.6960±0.0013 96.696 (fixed)	96.6960±0.0013	96.6963	96.7041±0.0031
Periastron Epoch (MJD)	48245.40±0.24	42056.32±0.20 51435.45±0.08	47374.77±0.15	49212.17±0.20
Eccentrcity	0.521±0.008 0.5366±0.0014	0.527±0.004	0.60±.02	0.555±0.013
Long of Periastron, deg	78.2±1.5	77.1±1.3 77.09±0.44	77.31±1.32	74.9±1.3
Inclination, deg	---------- 105.59±0.44	105.66±0.22	----------	----------
Position Angle of Node	----------	---------- 104.18±0.08	104.16±0.25	----------
Ang semimajor Axis (mas)	24.2±0.3*	---------- 24.25±0.25	24.15±0.13	----------
Mass of Primary, M_{sun}	3.60±0.20	---------- 3.8±0.2	3.8	5.5±0.5
Mass of Secondary, M_{sun}	1.78±0.08	---------- 1.9±0.1	1.8	2.3±0.2
Magnitude Diff (λ=nm)	----------	---------- ----------	1.99±0.04(550)	----------
(Secondary - Primary)	----------	---------- ----------	1.82±0.03(800)	----------
	---------- 1.57±0.04 (2200)	----------	----------	----------
K-band (	30.8±0.2		37.8±0.6	31.2±0.5

Pertinent Facts about PTI

- PTI is a 2-element interferometer described in detail by Colavita 1999a
- Located at Palomar Mountain, San Diego County, California
- 110-meter baseline oriented North-South (N-S) and 85-meter baseline North-West (N-W)
- In its 1999 only the N-S baseline was available for observing
- Provides H-Band (center: 1.6 μm) and CIT K-Band (center: 2.2 μm) visibility data
  - Alpha Andromedae was observed at both wavelengths
  - Analyses only used K-band data
- Yields a minimum fringe spacing of ~4.6 mas for the 110 meter baseline.

PTI Observables

- Visibility Squared
  - Fringe contrast of an observed brightness distribution on the sky
  - Normalized to [0:1]
  - Visibility modulus, V, for a single star in a uniform disk model is:

$$V = 2 J_1 (\pi B\theta/\lambda) / \pi B\theta/\lambda \qquad \text{(eq 1)}$$

J_1 = First Order Bessel Function

B = Projected baseline vector magnitude at the star position

θ = apparent angular diameter of star

λ = center-band wavelenth

  - Double star visibility squared in a narrow pass-band is:

$$V^2 = V_1^2 + V_2^2 r^2 + 2 V_1 V_2 r \cos(2\pi/\lambda \mathbf{B} \cdot \mathbf{s}) / (1 + r^2) \qquad \text{(eq 2)}$$

V_1 and V_2 = visibility moduli for each component

r = brightness ratio between primary and secondary

B = Projected baseline vector at the star position

s = primary-secondary angular separation vector on plane of sky

PTI Observables (2)

- Incoherent visibilities
  - PTI uses a fringe scanning technique dividing the signal into 4 bins to keep the delay line positioned and to compute the visibilities
  - PTI is not capable of unwrapping the phase so visibilities are incoherent
  - The K-band beam is divided into 2 paths:
    - One path is focused directly onto one pixel of a NICMOS detector (the so-called “wide band” pixel).
    - The other is passed through a single-mode fiber and a prism and divided into 5 pixels on the NICMOS detector (the so-called “spectral pixels” or “narrow-band channels”).
    - A synthetic “white light” visibility V^2_{WL} is computed by an incoherent SNR-weighted average of the narrow-band channels, V^2_{NB}

$$V^2_{WL} = 1/5 \sum V^2_{NB\text{-}i}(\lambda_i)$$

    - Wide band (2.0-2.4μm in K) visibilities V^2_{WB} are obtained from direct measurement of the “wide band” pixel.
    - The synthetic V^2_{WB} give superior fits to the data and is exclusively used in the analyses.

PTI Observables (3)

- Jitter correction
  - Delay line jitter, as measured in nanometers, are converted to phase errors in radians.
  - Jitter provides a measure of both the instrument and atmospheric stability for each observation.
  - It provides the formal errors in the visibility calculation.

Calibration

- Calibration is performed by comparing the target visibility with calibrator visibilities
  - Calibrators are single stars which are as point- like as possible, and of similar luminosity and spectral class as the target.
  - Visibilities of calibrators are measured in the same manner shortly before or after the target.
  - Stellar diameters are computed from the standard Bolometric Flux calculation for $T_{eff.}$
  - A Blackbody emission comparison is made to ensure normal behavior.
  - The calibrators allow a “system visibility” to be computed which tells the observer how an ideal point source would behave with the instrument and weather conditions at the time of the observation.
  - Delay line jitter corrections allow determination of formal error in the calibration.

Calibrator Selection

- HD166
  - Variable star - K0 V V_{mag} = 6.13 K_{mag} = 4.1
  - T_{eff} computed = 5262±54 °K
  - Angular Size computed = 0.67±0.06 mas
  - Angular separation from target = 0.39 degrees
- HD1404 (25 And)
  - Variable star - A2 V V_{mag} = 4.52 K_{mag} = 4.5
  - T_{eff} computed = 8900±0 °K
  - Angular Size computed = 0.50±0.05 mas
  - Angular separation from target = 8.0 degrees

Data Analysis

- HD 358 was observed 10 nights in the CIT K-Band (2.0-2.4 μm) over a 74-night period or about 76% of the orbital period.
- 250 25-second raw scans were processed into 50 calibrated, wide-band, incoherent V^2 calculations according to Colavita, 1999b.
- Orbit parameters were fitted to visibilities in equation (2) by the method given in Boden, 1999.
- V-K indices calculated from the V-band flux ratios from Pan 1992 and the K-band flux ratios in this study.
- Angular size is obtained from T_{eff}.
- Using semi-amplitudes from Ryabchikova (1999) and the PTI K-band solution provide the necessary parameters to obtain the distance, parallax and masses.

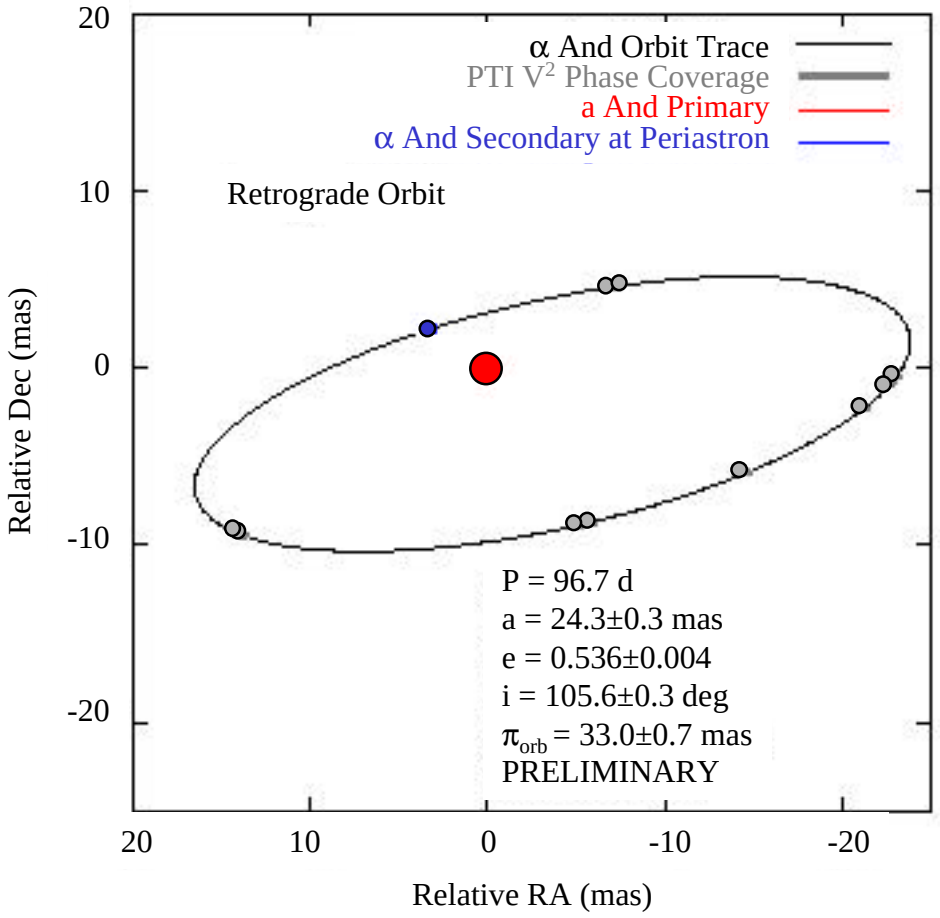
Results & Discussion

- Orbital Dynamics
  - Orbit fit starting point was from orbit data of Pan (1992)
  - Radial velocity data were obtained from Rybachikova (1999)
  - Periastron epoch (Modified Julian Date) = 51435.45±0.08
  - Results are shown in Figure 1 and compare better with Pan 1992 result than the Tomkin 1995 result.
- V - K index
  - The best-fit K-band intensity ratio, r in eq 2, is 0.234±0.006, which corresponds to a K magnitude difference of 1.568±0.035. This compares reasonably with the trend shown in the Pan 1992 intensity ratios of 0.160± 0.005 (1.99±0.04) at 550 μm and 0.188±0.006 (1.82± 0.04) at 800 μm.
  - From the V and K delta magnitudes, the computed V-K color indices for the primary is -0.41± 0.05 and for the secondary is +0.01±0.08. The primary color index seems a little smaller (more negative) than would have expected *a priori*, but within the error bar limit, the color index for the secondary (A2 V, Pan 1992) is approximately zero). The -0.41 V-K for the primary seems to be built into the system V-K of -0.34 (Simbad JP11 photometry; 2.06 and 2.40 for V and K, respectively).
- Distance, Parallax, Size, and Mass Computation
  - Using the semi-amplitudes of 31.2±0.5 and 62.8±1.5 from Ryabchikova (1999) (NOT an integrated V^2/RV solution) the K-band solution yields a distance estimate of 30.3±0.6 pc and parallax of 33.0±0.7 mas, which compares reasonably with the Hipparcos values of 29.8 ±0.7 pc and 33.6±0.7 mas, respectively).
  - Angular size = 0.80±0.01 mas as computed from T_{eff} of 13966 °K .
  - The resulting masses are 3.8±0.2 and 1.9±0.1 M_{sun}.

Table 2. α Andromedae Physical Parameters

Physical Parameter	Primary	Secondary
Mass, M_{sun}	3.8±0.2	1.9±0.1
Spectral Type	B8 IVmnp	A2 V
System Distance (pc)	30.3±0.6	
π_{orb} (mas)	33.6±0.7	
Model Diameter (mas)	0.80±0.01	----------
V-K (mag)	-0.41± 0.05	+0.01±0.08

Fig 1. Fitted orbit results



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- Literature and measurements surveys were performed with the aid of the SIMBAD data retrieval system and data base of the Strasbourg, France, Astronomical Data Center and NASA's Astronomical Data System (ADS)

Future Work

- Five other B (B0.5 V, B2 V, B3 IV, B3 V, and B6 V) and three O (O7e, O8e, O9 V) spectral class stars were observed in the 1999 season in survey mode. The results vary from